# DIPTERID FERNS FROM THE MESOZOIC OF ANTARCTICA AND NEW ZEALAND AND THEIR STRATIGRAPHICAL SIGNIFICANCE

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ABSTRACT. Two genera of dipteridaceous ferns, *Goeppertella* and *Hausmannia*, are described for the first time from the Mesozoic Hope Bay and Botany Bay assemblages of the northern Antarctic Peninsula, and *Goeppertella* from the Clent Hills assemblage of New Zealand. These are the first gondwanan records outside Argentina of *Goeppertella*. Two new species of the genus, *G. jeffersonii* and *G. woodii*, are described from Hope Bay and Botany Bay. Based on the global distribution of *Goeppertella*, its occurrence in these gondwanan floras indicates that they should be assigned an Early Jurassic or possibly earlier age, contrasting sharply with recently published Late Jurassic or Early Cretaceous age assignments. A pre-Late Jurassic age for the Hope Bay and Botany Bay assemblages is further supported by independent evidence from radiometric data. An earliest Cretaceous age for these assemblages has been adopted in most recent interpretations of volcanic arc evolution and palaeogeography in this region of Antarctica, the plant-bearing beds providing direct evidence of terrestrial sedimentation: these interpretations are revised here, based upon the new evidence. The ages assigned to a number of other late Mesozoic gondwanan floras, particularly from Argentina and India, must be reconsidered since many of these were dated on the basis of comparison with the Hope Bay assemblage.

BECAUSE of its great diversity and its early discovery and description (Halle 1913), the 'classic' fossil assemblage from Hope Bay, northern Graham Land, Antarctica (Text-fig. 1), has long been considered a standard for floristic and biostratigraphical studies on other Mesozoic gondwanan floras. Halle (1913) originally assigned a Middle Jurassic age to the assemblage, but it has subsequently been variously dated as Early Jurassic (Orlando 1971) or Middle Jurassic (Rao 1953), through to latest Jurassic or earliest Cretaceous (e.g. Stipanicic and Bonetti 1970b; Archangelsky and Baldoni 1972). A latest Jurassic or earliest Cretaceous age has been adopted in recent publications dealing with the palaeobotanical and geological history of the region (e.g. Baldoni 1981; Thomson *et al.* 1983; Farquharson 1983, 1984; Farquharson *et al.* 1984; Del Valle and Fourcade 1986; Macdonald *et al.* 1988).

The assemblage of two hundred and twenty hand specimens from Hope Bay, as described originally by Halle (1913), comprises fifty-nine species and two forms of unknown affinity, recently revised to forty-three by Gee (1989) based on Halle's specimens. The study of additional undescribed material, totalling some two thousand hand specimens, from Hope Bay and a new assemblage from nearby Botany Bay (Text-fig. 1B) has enabled an extensive revision of the Hope Bay assemblage (Rees 1990). The Botany Bay assemblage comprises thirty-one species, twenty-five of which also occur in the Hope Bay assemblage and they are so closely similar that they can be considered as having essentially the same age. The previously unrecorded presence of the dipteridaceous genus *Goeppertella* indicates an Early Jurassic or earlier age for these assemblages, with an Early Jurassic age being most likely on present evidence from the assemblages as a whole (Rees 1990). This is corroborated by recently published radiometric data (Millar *et al.* 1990) which provide evidence of a Jurassic, rather than Cretaceous, age for the assemblages. Interpretations of volcanic arc evolution and palaeogeography which utilized a latest Jurassic or earliest Cretaceous age for these assemblages must be revised; volcanic arc uplift commenced prior to terrestrial
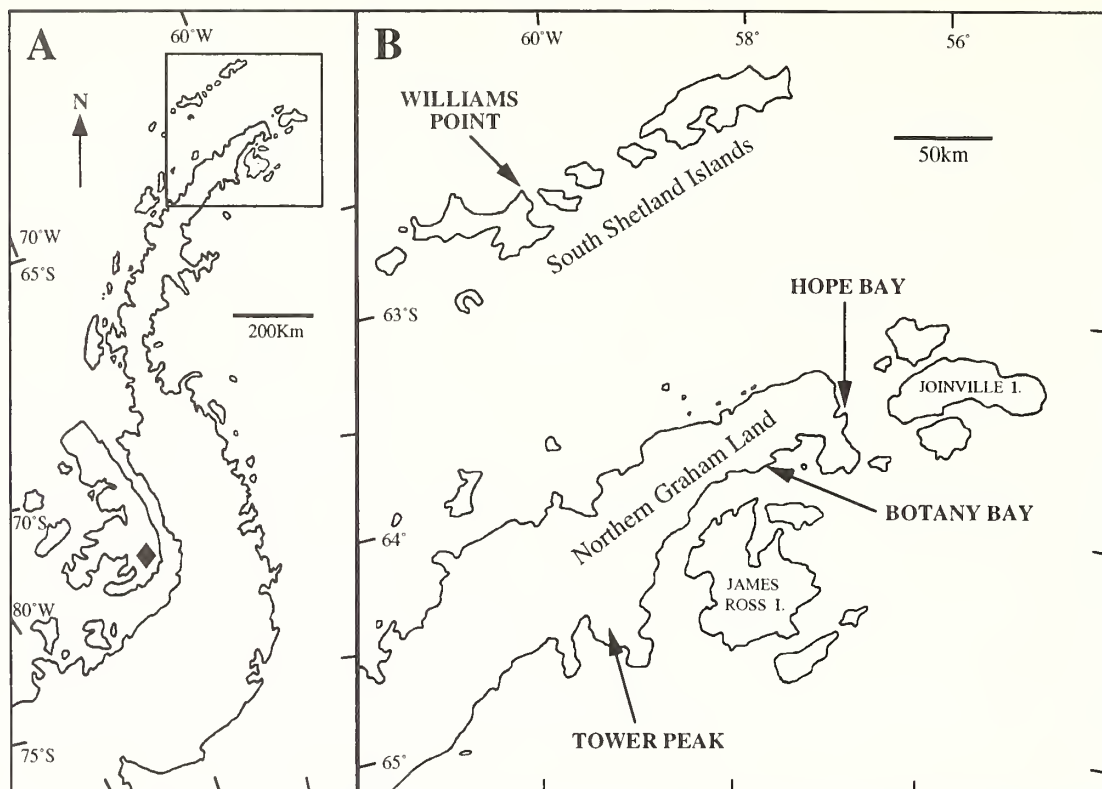
TEXT-FIG. 1. A, Antarctic Peninsula, showing location of main study area and the Cretaceous assemblage from Alexander Island (◆). B, principal Jurassic terrestrial deposits in northern Graham Land, as well as Williams Point (Cretaceous) in the South Shetland Islands.

deposition of the plant-bearing sediments in the Early Jurassic and not in the Early Cretaceous as believed previously (e.g. Farquharson 1984).

Two new species, *Goeppertella jeffersonii* and *G. woodii*, are described here from Hope Bay and Botany Bay, together with a specimen of *Goeppertella* from the Clent Hills assemblage of New Zealand, considerably extending the previously known gondwanan distribution of the genus. Another genus of the Dipteridaceae, *Hausmannia*, is also described for the first time from the Hope Bay and Botany Bay assemblages; this genus was only known previously in Antarctica from Alexander Island (Text-fig. 1A; Jefferson 1981).

MATERIAL AND METHODS

Fossil plant material was first collected from Hope Bay during the Swedish 1901–1903 expedition and has been studied and described by Halle (1913) and Gee (1989). It would appear that no other worker has directly studied the plants; certainly, no information from any subsequent collection has ever been published. British expeditions collected extensive additional material from Hope Bay during Operation Tabarin in 1945 and the Falkland Islands Dependencies Survey (FIDS) in 1946. Material was collected from the nearby Botany Bay locality by W. N. Croft (FIDS, 1946) and G. W. Farquharson (1979/1980 British Antarctic Survey (BAS) field programme); this has been supplemented by my own extensive collecting from Botany Bay, as part of the 1986/1987 BAS field programme. The material from these expeditions is housed in the Natural History Museum (prefixed V.), London, and forms part of the palaeobotanical collections of the British Antarctic

Survey; it has provided the basis of the present revision. The Antarctic specimens studied for this paper are numbered utilizing Natural History Museum registration numbers; they are listed, along with the equivalent British Antarctic Survey station numbers, in the appendix.

The plant material from both localities occurs as impressions and coalified compressions. In addition to diagenetic processes, it would appear that younger igneous intrusions have contact-metamorphosed the plant beds (Farquharson 1984). Identifiable palynomorphs have not been recovered from either locality (T. H. Jefferson *in* Farquharson 1984; D. Guy-Ohlson *in* Gee 1989; Rees 1990). The leaf cuticles have been converted to high-rank coal and cannot be prepared by conventional methods, although their original structure is occasionally preserved on impression surfaces, mainly on specimens from Botany Bay. Epidermal characters of such specimens could be examined and photographed directly, utilizing scanning electron microscopy. Macroscopic features of the specimens were enhanced by photographing them either under a thin coating of ammonium chloride or under cross-polarized light. The specimen of *Goeppertella* from New Zealand (also at the Natural History Museum) is similar to those from Hope Bay in preservation and was photographed only at the macroscopic level; no epidermal details are preserved.

SYSTEMATIC PALAEONTOLOGY

Order FILICALES Engler and Prantl, 1898–1902
Family DIPTERIDACEAE Seward and Dale, 1901

The fern family Dipteridaceae comprises several genera, which are distinguishable on the basis of their gross morphology and venation. Two of these, *Hausmannia* and *Clathropteris*, possess a lamina which ranges from being entire to weakly (and often irregularly) segmented. In the other genera segmentation is deeper and more consistent, producing more distinct frond-members which are separate to their bases and are more or less pinnate. Of these, *Thaumatopteris*, *Camptopteris* and *Dictyophyllum* possess frond-members which are characteristically once-pinnate (with pinnules arising directly from each frond-member), whereas in *Goeppertella* they are twice-pinnate (with each frond-member bearing pinnae, each pinna bearing pinnules). Additionally, vein meshes in *Hausmannia* and *Clathropteris* are typically rectangular; these are typically polygonal in the other dipteridaceous genera.

Problems can arise with fragmentary material which is not demonstrably bipinnate; for instance, when it is not known whether a fragment is a pinna of *Goeppertella* or a frond-member of *Dictyophyllum*. Such specimens from Hope Bay and Botany Bay can be assigned to *Goeppertella* on the basis of their close association with, and similarity to, more complete material from these localities which is assignable with confidence to this genus. The terminology used here in describing specimens of *Goeppertella* is explained in Text-figure 2.

Genus GOEPPERTELLA Ôishi and Yamasita, 1936

Type species. *Goeppertella microloba* (Schenk) Ôishi and Yamasita, 1936.

Previously recorded distribution. Late Triassic, possibly Early Jurassic, in the northern hemisphere; Early Jurassic in Argentina.
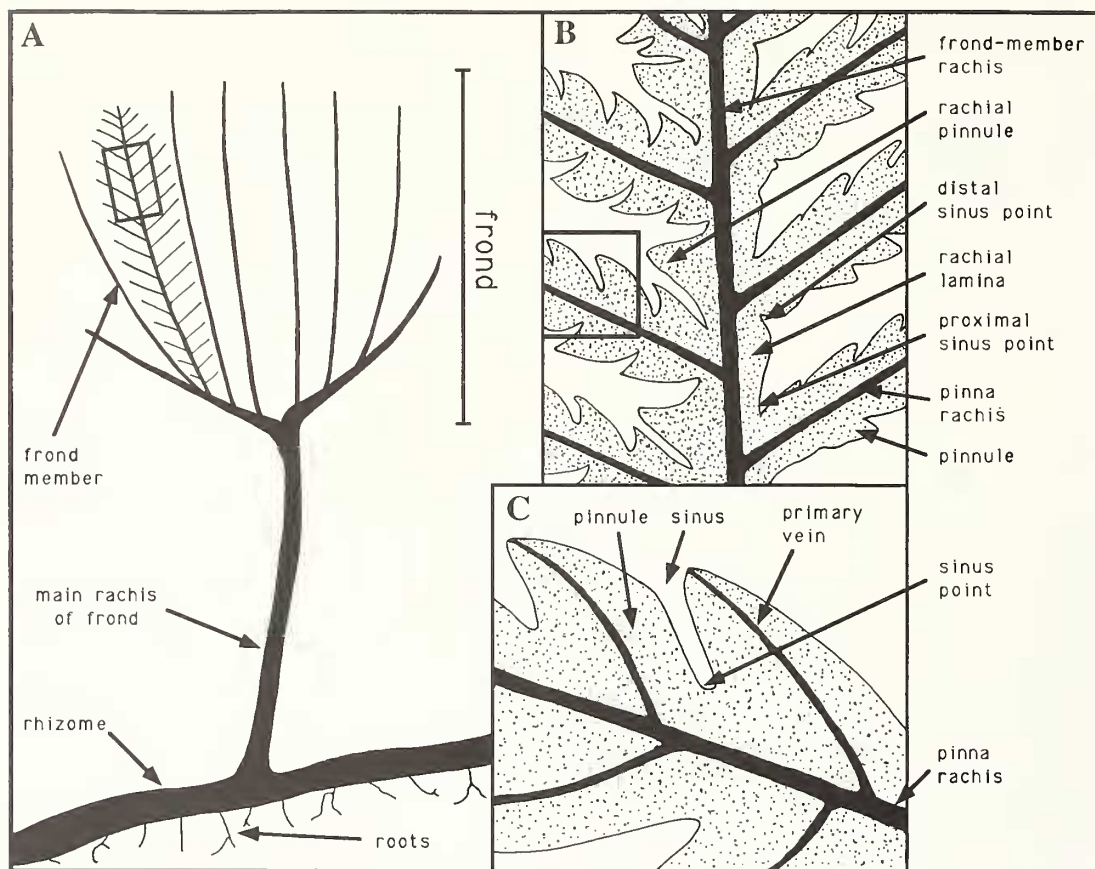
Goeppertella jeffersonii sp. nov.

Plate 1, figs 1–3; Plate 3, fig. 4; Text-fig. 3B

Derivation of name. For the late T. H. Jefferson, in recognition of his contributions to Antarctic palaeobotany.

Holotype. V.63595 from frost-shattered debris derived from the Camp Hill Formation, Botany Bay, northern Antarctic Peninsula (63° 41′ S; 57° 53′ W).

*Material.* From Botany Bay. V.63590–V.63597.

TEXT-FIG. 2. Schematic diagram explaining the terminology used here for *Goeppertella*. A, complete frond and frond rachis. B, portion of frond-member. C, portion of pinna. B and C are enlargements of the boxed areas in A and B respectively.

Diagnosis. Frond-member bipinnate; pinnae alternating regularly with well-defined rachial pinnules. Shape and size of rachial pinnules comparable to that of pinnules on pinna rachis; pinnules wedge-shaped, slightly falcate, 4–13 mm long × 2–8 mm wide, curving forward near their tips towards pinna apex. Pinnule apices acute to subacute, margins typically entire. Venation reticulate, poorly ranked, veins dividing to form polygonal vein meshes, first laterals branching uniformly from main vein, pattern not disrupted by rachial veins.

EXPLANATION OF PLATE 1

Figs 1–3. *Goeppertella jeffersonii* sp. nov.; Botany Bay. 1, V.63595; fragment near apex of bipinnate frond-member bearing pinnae and rachial pinnules, × 3. 2, V.63593; two bipinnate frond-members with pinnae bearing small pinnules, × 2·5. 3, V.63595; detail of pinnule morphology and venation, with the pinnule on the right showing marginal teeth on its basiscopic margin, × 10.

PLATE 1

REES, *Goeppertella*
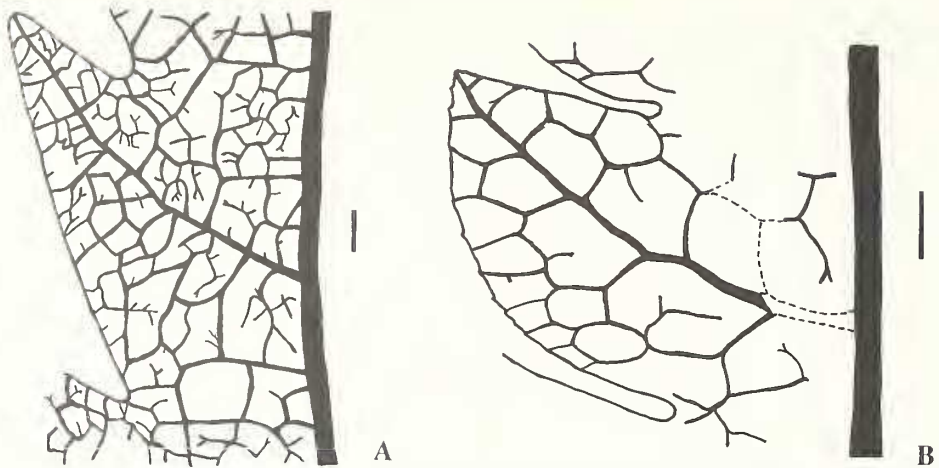
TEXT-FIG. 3. Pinnules of *Goeppertella* from Botany Bay, drawn from SEM montages, showing differing pinnule shape, size and venation. A, *Goeppertella woodii* sp. nov.; V.63610. B, *Goeppertella jeffersonii* sp. nov.; V.63595. Scale bars = 1 mm.

Description. Main rachis and overall form of frond unknown. Frond-member bipinnate, known mainly from fragments in its apical region. Member rachis stout, tapering in apical direction, up to at least 1·2 mm wide, its epidermis composed of elongate cells with scale bases occurring at irregular intervals of about 40–400 μm. Pinnae borne laterally in one plane, typically subopposite but occasionally alternate, at intervals of 12–15 mm (measured between pinna rachises) and at angles of 40°–80° to the member rachis, becoming more acute towards the apex of the frond-member. Pinnae ranging from an estimated 50 mm long (judged from taper of a pinna in the holotype) to at least 105 mm. Pinna rachis 0·1–1 mm wide (mostly $\leqslant$ 0·5 mm), typically straight but sometimes curving forward, especially in the region of the frond-member apex; epidermis like that of member rachis. Basalmost pinnule occurring on acroscopic side of pinna (based on three observations in two sufficiently complete specimens). Basalmost pair of pinnules smaller than more distal ones, which are of fairly uniform size until the pinna apical region where they become progressively smaller over a distance of *c.* 6–20 mm. Pinnules characteristically subopposite, rarely opposite or alternate, fully confluent in their proximal regions to form a continuous lamina bordering the rachis; pinnule lamina raised slightly. Pinnule length (measured along main vein from pinnule apex to rachis) ranging from 4 to 13 mm, mostly 5–11 mm, the shortest ones (4–5 mm long) occurring in the apical regions of the pinnae. Pinnule width (between sinus points) ranging from 2 to 8 mm, mostly 3·5–6 mm, the narrower pinnules (up to 4 mm wide) tending to occur near pinna apices. Ratio of pinnule length to width ranging from 1·4:1 to 2·9:1, mostly in range 1·6:1 to 2·2:1, not consistent with position of pinnules on pinna. Width of confluent lamina perpendicular between sinus point and pinna rachis ranging from 1 to 3 mm. Pinnules ranging from squat to relatively narrow but basically uniform, always forming wedge-shaped, slightly falcate segments which curve forward in the direction of the pinna apex, especially at their tips which are characteristically sub-acutely to acutely pointed to almost mucronate, rarely rounded. Pinnule margin normally appearing entire but occasionally very faintly and shallowly lobed; where exceptionally well-preserved, very finely denticulate at intervals of about 0·2 mm and showing distinct marginal vein.

Except at extreme apex of frond-member, where rachial lamina is absent, well-defined rachial pinnules occurring uniformly, one such pinnule occupying the gap between each successive pair of pinnae, its main vein departing from the member rachis at the same angle as the neighbouring pinna rachises. Shape and size of rachial pinnules (5–7 mm long × 3–6 mm wide) comparable with that of pinnules on pinna rachis, although rachial pinnules are often a little squatter (ratio of length to width *c.* 1:1 to 1·6:1), with more rounded and less falcate free portions. Rachial pinnules variously overlapping basal pinnules of the neighbouring pinnae, being confluent in their proximal regions bordering the member rachis; distance from sinus points formed between these two kinds of pinnules to the member rachis ranging from 1 to 2·5 mm.

Each pinnule on the pinna rachis supplied by a main vein up to 0·1 mm wide which runs to the pinnule apex and defines its long axis; main vein departing from rachis at acute angles of 40–60° near pinna apex, 50–90° (typically *c.* 60–70°) elsewhere, typically curving gently forward, especially in distal region of pinnule; following a slightly sinuous course, reflecting its branching, becoming finer and more frequently sinuous towards the pinnule apex. Coarse (first-order) lateral veins given off from main vein at intervals of about 1–3 mm and at angles of about 60°, branching and thinning to produce a reticulate network of anastomosing finer veins enclosing polygonal, 4–6-sided; islets of lamina about 0·5–1 mm in diameter but sometimes elongated up to about 3 mm long, about twice as long as broad. Other orders of venation not clearly delimited, islets in holotype often supplied by a blind-ending vein, either single or once-divided into a Y-shape. Epidermal cells poorly preserved, with coarsely sinuous walls of irregular shape, size and orientation. Stomata obscure but guard cells visible, about 30–50 μm long, apparently anomocytic, orientated in various directions. Cells over veins elongate, about 50–200 μm long × 10 μm wide. Fertile material unknown.

Discussion. The bipinnate organization of the frond-member is diagnostic of *Goeppertella* within the Dipteridaceae, it being the only member of the family which shows this feature (see Arrondo and Petriella 1982 for further discussion). The type of 'intercalary element' (= rachial pinnule or lamina) has been used by Arrondo and Petriella (1982) to distinguish species of the genus. Certain other characters serve to separate these species; pinnule shape and orientation on the pinna rachis, the style of pinnule apex (i.e. whether acute or obtuse), pinnule size and the type of margins (i.e. whether entire or undulating).

Eight species of *Goeppertella* have been described previously (Arrondo and Petriella 1982 and references therein). Of these, *G. jeffersonii* bears most resemblance to *G. frenguelliana*, *G. microloba*, *G. macroloba* and *G. neuqueniana*. The style of rachial lamina and pinnule size distinguishes it from *G. frenguelliana*, which has a greatly reduced lamina, while *G. microloba* has differently-shaped pinnules which have undulating margins. *G. macroloba* possesses pinnules which are considerably larger than those of *G. jeffersonii*, whereas pinnules of *G. neuqueniana* are longer (with higher length to width ratios) and have obtuse rounded apices. Additionally, pinnules of *G. neuqueniana* are typically separate from one another on the pinna rachis, only becoming confluent in apical regions of the pinna. The rachial pinnules of *G. microloba*, *G. macroloba* and *G. neuqueniana* are less pronounced than those of *G. jeffersonii*, being little more than small lobes in the central regions of the rachial laminae.

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Goeppertella woodii sp. nov.

Plate 2, figs 1–4; Plate 3, figs 1–3, 5; Text-fig. 3A

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1913   *Dictyophyllum* sp.; Halle, text-fig. 2, pl. 1, figs 28, 28a.
1989   *Dictyophyllum* sp.; Gee, pl. 2, fig. 13.

Derivation of name. For P. Wood, who was my companion in Antarctica and ensured the success and safety of our field season.

Holotype. V.63602 from the Camp Hill Formation, Botany Bay, northern Antarctic Peninsula (63° 41′ S; 57° 53′ W).

Material. From Hope Bay – V.63598, V.63599; from Botany Bay – V.63600 to V.63619.

Diagnosis. Frond-member bipinnate. Pinnae alternating with rachial lamina; lamina shape irregular, but always broadening from proximal to distal sinus points, occasionally lobed distally. Pinnules wedge-shaped, strongly falcate, relatively narrow in free portions, 6–25 mm long × 5–13 mm wide, curving towards pinna apex. Pinnule apices acute to subacute, margins typically entire. Venation reticulate; first-order lateral veins arising from main vein, joining with veins arising from rachis between pinnules, dividing to form polygonal vein meshes. Fertile segments with sori typically on rachial lamina and pinnule bases; sori 0·7–1 mm across, comprising ten or more sporangia *c.* 0·1 mm in diameter.

Description. Main rachis and overall form of frond unknown. Frond-member bipinnate, large, known from fragments both of the apical region and more proximally. Member rachis stout, tapering distally, up to at least 3 mm wide; longest length preserved, 120 mm. Epidermis of member rachis composed of both short and elongate cells with no clear evidence of scale bases. Pinnae borne laterally in one plane, typically sub-opposite, occasionally alternate or opposite, at intervals (measured between pinna rachises) of 11 mm to at least 40 mm (mostly 12–20 mm) and at angles of 30–75° (mostly 40–60°) to the member rachis. Pinna separation and angle of attachment to the member rachis decreasing towards the apical region of the frond-member; greater pinna separation and angle from the rachis associated with thicker member rachises (presumed to be from more proximal regions of the frond-member). Measured pinnae up to 90 mm long, overall length ranging from an estimated 80–100 mm up to more than 150 mm (judged from taper of pinna rachis). Pinna rachis gradually tapering distally, from 0·2 to 1·3 mm wide (mostly 0·2–0·8 mm), typically straight but sometimes curving forward in the apical region of the frond-member to become subparallel to the frond-member rachis. Epidermis of pinna rachis like that of frond-member, occasionally with oval pits, presumably scale bases, 50–200 μm long.

Basal pinnules of pinna are usually smaller and less pronounced than more distal ones (with the exception of those in the apical 20–30 mm of pinna). Pinnules characteristically subopposite, sometimes opposite or alternate, fully confluent in their proximal regions to form a continuous lamina bordering the rachis; pinnule lamina raised slightly. Pinnule length (measured along main vein from pinnule apex to rachis) ranging from 6 to 25 mm, mostly 12–18 mm. Pinnule width (between sinus points) ranging from 5 to 13 mm, mostly 9–11 mm. Ratio of pinnule length to width ranging from 0·9:1 to 2·3:1, mostly in range 1·1:1 to 1·4:1, not consistent with position of pinnules on pinna. Width of confluent lamina perpendicular between sinus point and pinna rachis ranging from 2 to 11 mm, mostly from 3·5 to 7 mm. Pinnules wedge-shaped, ranging from squat (especially on more proximal pinnae of the frond-member) to, characteristically, relatively narrow in their free part, strongly falcate, usually pointing strongly towards pinna apex, especially at their tips which are typically acutely to subacutely pointed. Free regions of pinnules only rarely overlapping neighbouring ones but often somewhat overlapping pinnules of neighbouring pinnae. Pinnule margin entire, occupied by a marginal vein.

Interval between successive pinnae occupied by a rachial lamina except in extreme apical region of frond-member, where rachial lamina is absent. Rachial lamina irregular in size and shape, but always broadening from proximal pinna sinus point to just before the next more distal one, with the development in some cases of a pinnule-like lobe (rarely, two, with the distal lobe being more pronounced). In other cases the lamina broadens only slightly, occasionally being indistinguishable from the basal basiscopic pinnule of the next distal pinna. Lamina ranging from 1 to 5 mm wide between proximal sinus points and member rachis, broadening to 3–7 mm between next distal sinus points and rachis; distance between sinus points from 10 to 25 mm. Lobes, where developed, from 6 to 13 mm long (measured from lobe apex to member rachis), symmetrical or curving gently forward with rounded or pointed apices; lobe main veins arising from member rachis at 60–90°, producing higher-order veins which divide in a similar manner to those of the pinnules on the pinnae.

Each pinnule supplied from pinna rachis by a main vein up to 0·1 mm wide which runs to the pinnule apex and defines its long axis; main vein departing at angles of 40–90°, curving forwards to 0–40° near pinnule apex. Main vein often slightly sinuous owing to lateral veins being given off. First order lateral veins arising at intervals of about 1·5–3 mm, often at 90° or backwardly directed, joining with veins of similar strength given off directly at 50–90° and at intervals of 2–5 mm from the pinna rachis to form a characteristic coarse mesh (each *c.* 1–3 mm in diameter). First-order laterals producing second-order veins which anastomose to form a fine mesh of polygonal, 4–6-sided islets of lamina about 0·25–0·5 mm in diameter. Veins with elongate cells. Epidermal cells poorly preserved, with coarsely sinuous walls of irregular shape, size and orientation. Stomata not clear.

PLATE 2

REES, *Goeppertella*

Some frond-members and pinnae fertile, usually bearing sori within 0–5 mm of their rachises, with fewer present further out on the pinnules, becoming rare or absent at extreme apex of pinnules. Occasionally, neighbouring sori grouped together to produce appearance of one large or long sorus. Sori round to ovate, c. 0·7–1 mm across, comprising at least ten sporangia c. 0·1 mm in diameter; sporangia coalified.

Discussion. Goeppertella woodii differs from *G. jeffersonii* primarily in having an irregular rachial lamina rather than rachial pinnules. Additionally, pinnules on pinnae of *G. woodii* are larger, more falcate and generally narrower than those of *G. jeffersonii*. The rachial lamina of *G. woodii*, which is irregular in size and shape, but which always broadens from the proximal sinus point to the distal point, is unlike any seen in the eight species of *Goeppertella* described previously (Arrondo and Petriella 1982 and references therein). Of these species, *G. woodii* is most similar to *G. frenguelliana* and *G. macroloba*. However, the rachial lamina is greatly reduced in *G. frenguelliana*, being present only as a narrow strip with margins which are parallel to the frond-member rachis, while the lamina in *G. macroloba* is broadest in its central region, not distally as in *G. woodii*. The Dipteridaceae were only known previously at Hope Bay from one poorly-preserved pinna fragment, comprising three incomplete pinnules, which Halle (1913) and Gee (1989) assigned to *Dictyophyllum* sp. The specimen which they described is closely similar in pinnule shape, size and venation pattern to more complete material assigned here to *G. woodii* and can be included within this species.

### *Goeppertella* cf. *woodii* sp. nov.

Text-fig. 4

Material. V.15719 from Haast Stream in the Clent Hills of South Island, New Zealand (collected in 1911 by D. G. Lillie).

Description. Main rachis and overall form of frond unknown. Frond-member bipinnate, member rachis up to 1·2 mm wide, 47 mm long, bearing three pinnae. Pinnae subopposite, arising at angles of 45–60° to member rachis, one pinna 40 mm long (complete to apex), another > 40 mm (incomplete); pinna rachises up to 0·3–0·5 mm wide. Pinnules subopposite, falcate, main veins departing at 50–90° from pinna rachis, margins entire, apices sub-acutely to acutely pointed. Pinnule length (measured along main vein from pinnule apex to rachis) ranging from 7 to 13 mm (non-apical pinnules). Pinnule width (between sinus points) ranging from 4 to 10 mm. Width of confluent lamina perpendicular between sinus point and pinna rachis 3–5 mm. Rachial lamina incompletely preserved, but broadens distally from proximal sinus point towards distal point, with a distinct distal pinnule-like segment, 7–8 mm long, given off at 60–90° from the member rachis. Pinnule venation similar to that seen in specimens of *G. woodii* from Antarctica. Epidermal and fertile details not known.

Discussion. This single specimen is most similar to *G. woodii*, agreeing in the style of its rachial lamina and its pinnule size and shape as well as in the orientation of pinnules on the pinna rachis and in venation pattern. As with *G. woodii*, it differs from the species described previously (Arrondo and Petriella 1982) in the shape of its rachial lamina, which always broadens distally. Although

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EXPLANATION OF PLATE 3

Figs 1–3, 5. *Goeppertella woodii* sp. nov.; Botany Bay. 1, V.63602; fragment near apex of bipinnate frond-member bearing pinnae and rachial lamina, × 1. 2, V.63614; fragment probably from proximal region of a frond-member (the rachis either having been distorted during development of the frond or during deposition), × 1. 3, V.63613; pinna fragments, the uppermost one being attached to a short length of frond-member rachis at the extreme right of the block, with large pinnules bearing sori visible as dark patches on their surfaces, × 1. 5, V.63603, impressions of sori on a fertile frond-member showing annulus cells in a near-vertical annulus, × 25. Fig. 4. *Goeppertella jeffersonii* sp. nov.; Botany Bay; V.63595; pinnule venation and impressions of stomata, showing largely vertically aligned stomata and guard cells, × 90.

PLATE 3

REES, *Goeppertella*
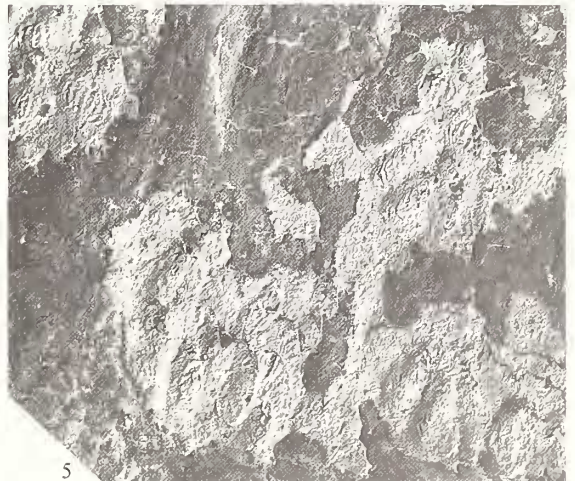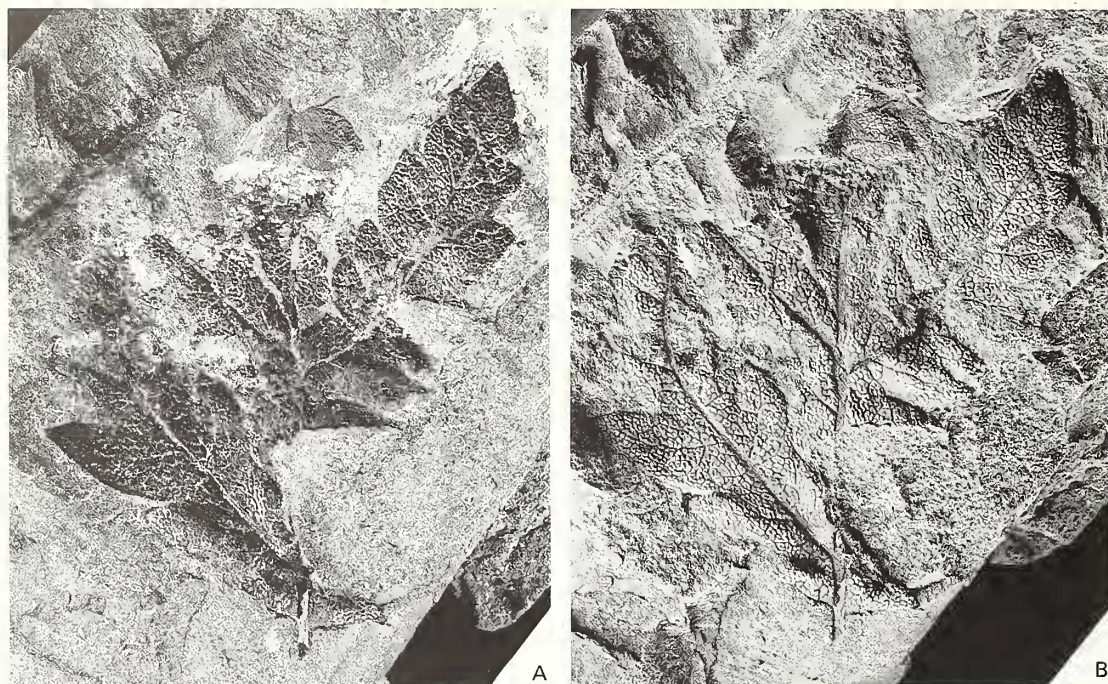
TEXT-FIG. 4. *Goeppertella* cf. *woodii*. V.15719; Clent Hills, New Zealand. A, bipinnate frond-member photographed under cross-polarized light, showing the overall form of the pinnae and pinnules, × 1·25. B, the same specimen coated with ammonium chloride, showing rachis and venation details, × 1·25.

pinnules on the pinnae of this specimen are similar in size to those of *G. jeffersonii*, the rachial lamina is markedly different from the rachial pinnules seen on the frond-members of the Antarctic species. The specimen is assigned here to *G.* cf. *woodii* until further material is available to confirm its identity.

Genus HAUSMANNIA Dunker, 1846

*Type species. Hausmannia dichotoma* Dunker emend. Harris, 1961.

Hausmannia cf. *nariwaensis*

Text-fig. 5

1981   DICTYOPHYL-PHOBOS Jefferson, pl. 4.12, figs 1–2 (not figs 3–5).

Material. From Hope Bay – V.63420, V.63423, V.63620; from Botany Bay – V.63621–V.63623.

Description. Rachis not known, but region of rachial attachment seen in centre of complete lamina. Complete lamina heart-shaped, up to 52 mm long × 43 mm wide, divided along its length into two main, almost identical, lobes (incomplete lamina lobes seen, up to 95 mm long). Broadest point of lamina at about one third the distance from the proximal to distal end, thereafter narrowing gradually until near the distal end. Proximal half of lamina divided deeply to point of rachis attachment along lamina midline, the opposing margins of the two lobes almost in contact or slightly overlapping along three fifths of the midline, then diverging to form the two rounded proximal lobes of the lamina. Distal half of lamina divided from the distal end to half way to the point of rachis attachment, divided distally into two rounded lobes which are narrower and less pronounced than the proximal ones. Lamina margin entire within clefts between the two main lobes; elsewhere, markedly
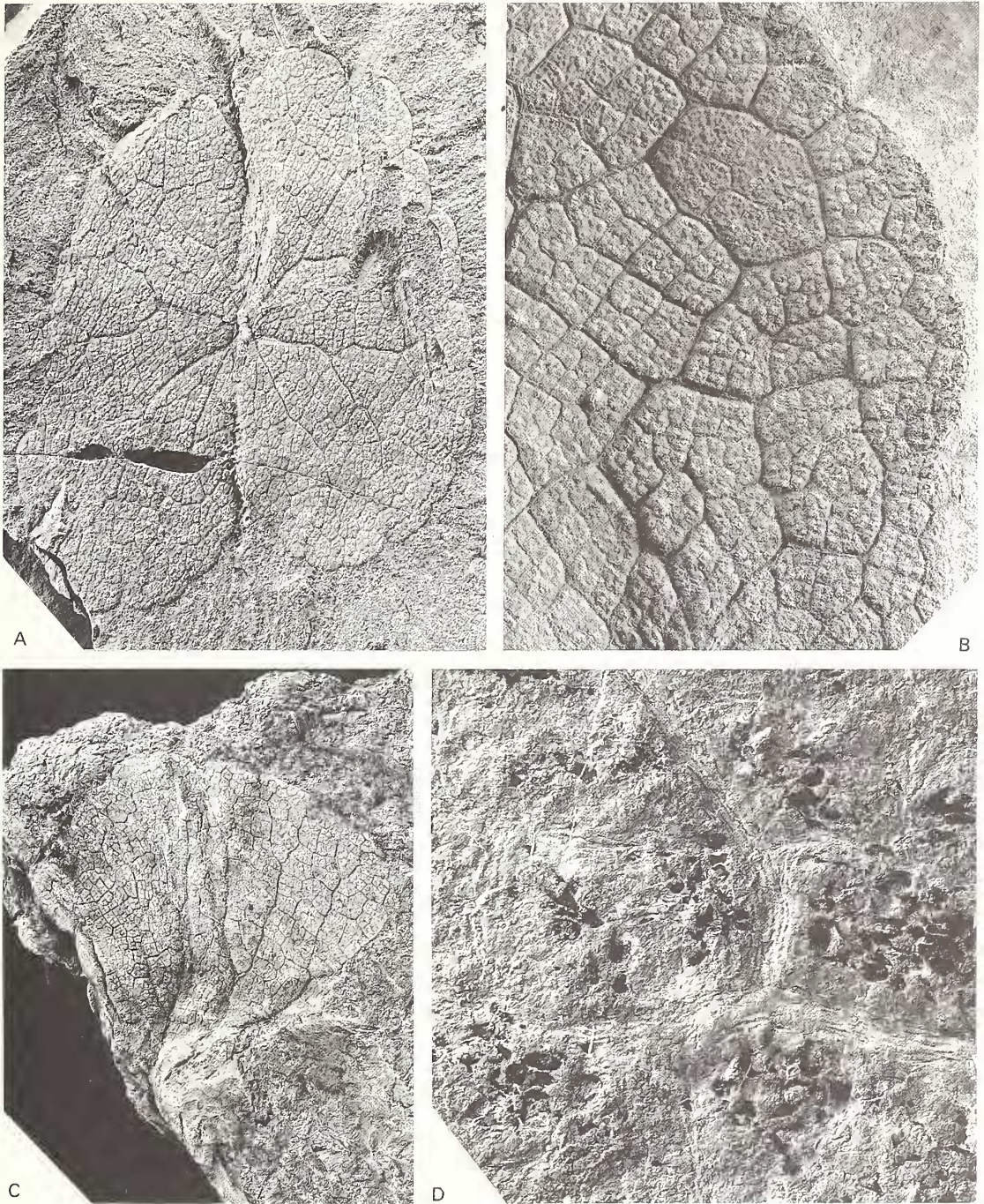
TEXT-FIG. 5. *Hausmannia* cf. *nariwaensis*. A, NHM V.63620; near-complete fertile lamina and region of rachis attachment, × 1·5. B, NHM V.63420, fragment of large lamina with pronounced venation, showing vein orders and areas with sori, × 5. C, NHM V.63623, fragment of fertile lamina, × 2. D, NHM V.63623, detail of C showing venation and sori, × 50. A–B from Hope Bay; C–D from Botany Bay.

crenulate, shallowly divided into convex lobes 0·5–1·5 mm deep, of variable length (from 4 to 12 mm) between the main sinus points, several lobes with shallow medial sinus points indicating smaller lobes 2·5–5·5 mm long; marginal vein evident, c. 0·1 mm wide.

In each half of the lamina, four main veins up to 0·2 mm wide radiate from the point of attachment to the rachis, reaching to the margin and following a sinuous course as the various laterals are given off. Dichotomous branching of main veins occurring at varying intervals, up to 10 mm apart, forming large-scale (first-order) meshes; these are triangular through rectangular to polygonal (rarely more than pentagonal), often with sides of variable length, shortest dimension about 3 mm, longest up to 15 mm. Within these first-order meshes, thinner secondary vein branches arise from the main veins and anastomose to form secondary meshes of fairly regular size, typically 1·5–4 mm long × 1–2·5 mm wide; these have 3 to 6 (rarely, 7) sides but are most commonly rectangular. These meshes are traversed by finer veins which form third order meshes, 3 to 7 sided but mostly rectangular, up to 1·5 mm × c. 0·5–1 mm. Occasionally, third-order veins dividing to form fourth-order meshes which are mostly rectangular and from 0·5 to 1 mm long. A fifth order of venation may be present in places, but divisions are unclear. Third-order meshes (or fourth-order, where seen) often occupied by a rounded to oval sorus about 0·8 mm across, with a central receptacle and several sporangia (details obscured by coarseness of matrix and/or coalification); epidermal details obscure, veins with elongate cells.

Discussion. *Hausmannia* is represented in the Hope Bay and Botany Bay assemblages by several fragments of laminae and one near-complete lamina; it has not been described previously from these localities. The specimens are similar to *H. nariwaensis*, described from Rhaetic floras of Japan (Ôishi 1932). They differ in the shape of the lamina, which is reniform (with the long axis perpendicular to the median cleft) in the Japanese specimens and heart-shaped (the long axis being parallel to the cleft) in the material from Hope Bay and Botany Bay. Further material is required from these Antarctic localities in order to assess the significance of this difference, although the specimens can be assigned to *H.* cf. *nariwaensis* on the basis of the close similarity in lamina division, marginal lobing, venation pattern and soral details. *Hausmannia ussuriensis*, described by Kryshtofovich (1923) from Rhaeto-Liassic rocks in Eastern Siberia is also similar to the material described here but appears to have coarser and more numerous main veins, as well as a reniform lamina. *Hausmannia deferrariisii* Feruglio (1937) from Argentina and *Hausmannia* sp. cf. *H. deferrariisii* described by Herbst (1979) from Australia differ from the Antarctic material in having a reniform lamina which, in addition, is less evenly incised. The only previous Antarctic record of the genus is from the ?Aptian–Albian assemblage of Alexander Island (Text-fig. 1A), the material being assigned to a biorecord, DICTYOPHYL-PHOBOS, by Jefferson (1981). The specimens from Hope Bay and Botany Bay can be assigned to the same species as some of those described from Alexander Island (Jefferson 1981, pl. 4.12, figs 1–2), since they are almost identical in lamina size, shape and marginal lobing, as well as in venation pattern and soral details. However, the shape of the lamina, as well as the marginal lobing and venation, differs in the other specimens figured by Jefferson (1981, pl. 4.12, figs 3–5) and they possibly represent a different species of *Hausmannia*.

AGE OF THE HOPE BAY, BOTANY BAY AND CLENT HILLS ASSEMBLAGES

Age ranges of Goeppertella *and* Hausmannia

The only previous records of *Goeppertella* in the southern hemisphere are from beds in Argentina dated as Early Jurassic (Herbst 1964, 1966, 1975; Arrondo and Petriella 1982 and references therein; Baldoni 1987). Of the five Argentine species of the genus, two were assigned Early Jurassic ages on the basis of the plants themselves, in the absence of independent age constraints such as radiometric dating, palynology or marine faunas used to date the other three species (see Rees 1990 for details). It remains possible that these two Argentine species may be younger than Early Jurassic, although they would be the first records of such an occurrence. Indeed, most species of *Goeppertella* from the northern hemisphere are of Late Triassic age, with the possibility of some ranging into the lower part of the Early Jurassic and none being known from younger floras (e.g. Möller and Halle 1913; Ôishi and Yamasita 1936 and references therein; Harris 1946). It is apparent

that *Goeppertella* is represented globally in strata which have a published age range of Late Triassic to uppermost Early Jurassic and it has not been shown to occur in younger floras.

Unlike *Goeppertella*, *Hausmannia* is of limited stratigraphical value, being represented in floras of latest Triassic and earliest Jurassic age (e.g. Kryshtofovich 1923; Harris 1931; Ôishi 1932) through to those of Early Cretaceous age (e.g. Seward 1913; Watson 1969; Jefferson 1981).

Age of the Hope Bay and Botany Bay assemblages

An earliest Cretaceous age for the Hope Bay and Botany Bay assemblages has been used in most recent interpretations of Mesozoic volcanic arc evolution and palaeogeography in the northern Antarctic Peninsula region (e.g. Farquharson 1984), with the palaeobotanical paper by Stipanicic and Bonetti (1970b) being the most frequently cited. Since the new evidence for an Early Jurassic age contradicts previous arguments, the principal ones are reviewed here (see Rees 1990 for a detailed account).

Stipanicic and Bonetti (1970a, 1970b) reviewed the Argentine Jurassic floras and included (1970b) a discussion of the affinities and age of the Hope Bay plants. They concluded that they show an equal degree of affinity with what they believed to be the Lower Cretaceous Rajmahal floras of India as with those from the Middle Jurassic and Neocomian of Europe. For this reason, the authors estimated that the Hope Bay assemblage was of latest Jurassic age, without discounting the possibility that it could even be earliest Cretaceous. However, it would appear that their age argument has two significant problems. Firstly, the Indian Rajmahal floras are imprecisely dated and can only be reasonably assigned an age of ?Early Jurassic to ?Albian. An Albian age for the Rajmahal plants is based upon the 100–105 Ma K-Ar dates for lavas which were believed to be of the same age as the plant beds (McDougall and McElhinny 1970). Shah *et al.* (1973) considered that the only criterion for determining the age of the Rajmahal Plant Beds was the plant remains and concluded that they are of Early to Middle Jurassic age. Sengupta (1988, p. 154) discussed the reasons for the contradictory radiometric (Early Cretaceous) and palaeobotanical (Jurassic) results for the age of the Rajmahal flora. He argued that, although some samples of Rajmahal basalt (e.g. those dated by McDougall and McElhinny 1970) indicated a Cretaceous age, their stratigraphical and geographical location is poorly defined and cannot be used to assign a lower age limit to the Rajmahal Formation. Sengupta (1988) concluded that the Rajmahal Formation may be considered as Middle Jurassic to Cretaceous. Given the uncertainty concerning the age of this and other Indian late Mesozoic plant-bearing sequences any age assignment based upon a correlation with them is questionable. Secondly, it is difficult to accept that late Mesozoic floras from widely differing palaeolatitudes (e.g. Antarctica and northern Europe) can be correlated and used with confidence for stratigraphical purposes. When this type of correlation is carried out, it should be made clear that further refinement, based upon local correlations, will be needed. For example, an impression/coalified compression assemblage within the Fossil Bluff Formation on Alexander Island, west of the Antarctic Peninsula (*c.* 71° S, 67° W; Text-fig. 1A) has been independently dated as ?Aptian–Albian on the basis of the presence of marine invertebrate fossils in the formation. The assemblage contains twelve taxa which are morphologically similar to those from the Aptian of Victoria, southern Australia, but it also has nine morphologically similar taxa in common with the Middle Jurassic flora of Yorkshire, England (Jefferson 1981). If the floras from Victoria had not been known to Jefferson, he may have concluded that the greatest affinity of the Alexander Island flora was with that from Yorkshire. A Middle Jurassic age could then have been assigned to the Cretaceous Alexander Island flora on palaeobotanical grounds. It appears that because Stipanicic and Bonetti (1970b) did not compare the Hope Bay plants with more local assemblages (particularly those from Argentina), they assigned a latest Jurassic–earliest Cretaceous age to what is shown here to be an Early Jurassic flora. It is interesting that Bonetti, both previously (1963) and subsequently (1974), recognized the close similarity between the plants from Hope Bay and Argentina and assigned ages to the latter based upon their close similarity with the assemblage from Hope Bay.

Farquharson (1984) assigned the Hope Bay and Botany Bay plant-bearing beds to the Botany Bay Group (BBG). The BBG was defined by Farquharson (1984, p. 28) as comprising 'outcrops of non-marine, mainly conglomeratic, sedimentary rocks derived from deformed metasedimentary rocks...[which] form a significant tectono- and litho-stratigraphic unit in the northern Antarctic Peninsula'. Farquharson (1984) cited three lines of evidence for an earliest Cretaceous age for the BBG.

Firstly, he cited the palaeobotanical arguments put forward by Stipanicic and Bonetti (1970b) for a latest Jurassic or earliest Cretaceous age for the Hope Bay assemblage. As demonstrated above, however, these arguments cannot be used as evidence for this age.

Secondly was the presence of a marine intercalation within alluvial fan conglomerates in the South Orkney Islands which Farquharson (1984) had included in the BBG; the marine sequence contains ammonites indicative of an Early Cretaceous age (Thomson 1981). This age cannot be used reliably to date what are merely lithologically-similar sequences from BBG localities elsewhere.

Thirdly, they used two radiometric ages of 130 ± 7 Ma and 117 ± 4 Ma obtained by Pankhurst (1982) for rocks of the Antarctic Peninsula Volcanic Group (APVG); volcanic rocks of the APVG overlie, or are commonly interbedded with, sedimentary sequences of the BBG. The Early Cretaceous ages for rocks of the APVG from two localities in the region were used by Farquharson (1984) to indicate a similar age for all of the BBG sequences. However, the relationship of these dated volcanic rocks with those of the Botany Bay Group is uncertain, since they are not in contact with them. Furthermore, Thomson and Pankhurst (1983, p. 328) remarked that 'some caution is necessary in accepting these ages since Rb–Sr whole-rock systems in acid volcanic rocks are widely considered to be very easily reset without metamorphism'.

It can be seen that the evidence presented here for an Early Jurassic age for the Hope Bay and Botany Bay assemblages outweighs that used previously to assign an earliest Cretaceous age to these plants and to the Botany Bay Group as a whole. Significantly, new radiometric data indicate an upper Middle or Late Jurassic age at youngest for the plants from Hope Bay and Botany Bay. At Botany Bay, Sm–Nd dating of primary igneous garnets (from an andesitic sill within volcanic rocks of the Antarctic Peninsula Volcanic Group) has yielded an age of 152 ± 8 Ma; this age is believed to indicate the time of intrusion of the sill (Millar et al. 1990). This corresponds to an age of lower Callovian to lower Berriasian (Harland et al. 1982) or upper Bathonian to lower Kimmeridgian (Haq et al. 1987). Thus, emplacement of the sill probably occurred sometime during the upper Middle or Late Jurassic. The volcanic rocks (including the dated sill) overlie the plant-bearing sedimentary sequence at Botany Bay (See Rees 1993 for further discussion). The close similarity between the Botany Bay and Hope Bay assemblages indicates that the Hope Bay plants can be assigned the same age as those from Botany Bay. The results of the radiometric dating (Millar et al. 1990) are consistent with the revised age presented here for the Hope Bay and Botany Bay assemblages and confirm that they should no longer be regarded as Cretaceous.

The new data cast considerable doubt upon the earliest Cretaceous age which was previously assigned to all of the beds and formations included within the Botany Bay Group (e.g. Farquharson 1984). Indeed, it now seems probable that the BBG comprises sediments which were deposited in discrete terrestrial basins during the Early Jurassic (Hope Bay and Botany Bay), with sedimentation possibly continuing into the Early Cretaceous (South Orkney Islands). Although Farquharson (1984) remarked that sediments from different outcrops of the Botany Bay Group may not have been deposited contemporaneously, he was clearly not implying that their deposition spanned the Early Jurassic to Early Cretaceous.

Age of the Clent Hills assemblage

Oliver et al. (1982) assigned a possible Middle to Late Jurassic age to the Clent Hills Group in the Mount Somers area of South Island, New Zealand. They recognized two units within the group, one non-marine and the other marine. The non-marine sequence is best represented at the Haast Stream locality and contains the most abundant fossil plants, although no palynomorphs or macrofauna

have been found. Several workers have collected or identified plants from this locality and have variously assigned Triassic or Jurassic ages (e.g. Haast 1877; Ettingshausen 1891; Arber 1917; Edwards 1934). The plants were assigned Jurassic ages by Oliver *et al.* (1982), who believed they could not be assigned precise time-ranges. Microfloras have been discovered at two other non-marine localities in the area and have been dated as Middle to Late Jurassic and Early Jurassic to Early Cretaceous (Oliver *et al.* 1982 and references therein); their relationship to the macroflora in Haast Stream is uncertain. The Middle to Late Jurassic age which Oliver *et al.* (1982) assigned to the Clent Hills Group as a whole was based principally upon ages of invertebrate fossils from marine sequences in the area. Significantly, the relationship between these sequences and those with identifiable plant macrofossils is unknown, due to limited exposure and the absence of localities showing gradations between the macrofloral and macrofaunal sequences. *Goeppertella* had not been identified previously from any of the Clent Hills sequences. Its occurrence in the Haast Stream assemblage indicates that the latter can be assigned a Late Triassic or Early Jurassic age. Consequently, the stratigraphy of the Clent Hills Group should be reconsidered, since it now comprises one non-marine sequence (and possibly more) of Late Triassic or Early Jurassic age as well as Middle to Late Jurassic marine sequences.

CONCLUSIONS

The bipinnate specimens described here can be assigned with confidence to *Goeppertella*. The previously recorded age range of the genus is from Late Triassic to uppermost Early Jurassic. It remains possible that the new specimens (from Hope Bay, Botany Bay and Haast Stream) may represent occurrences of the genus outside this range. However, the recent radiometric data of Millar *et al.* (1990) indicate an upper Middle or Late Jurassic age for the volcanic rocks which overlie the plant beds at Botany Bay. Also, previous arguments for a latest Jurassic or Early Cretaceous age for the Hope Bay and Botany Bay assemblages (based upon palaeobotanical, sedimentological and radiometric evidence) do not stand up to critical appraisal. It is concluded that an Early Jurassic age assignment for the Hope Bay and Botany Bay assemblages is most likely on present evidence. Certainly, they should no longer be regarded as latest Jurassic or Early Cretaceous.

The Hope Bay and Botany Bay leaf fossils are now the oldest known from this area of Antarctica since the assemblage from Williams Point, previously assigned a Triassic age (e.g. Lacey and Lucas 1981; Banerji and Lemoigne 1987), is now shown to be Cretaceous (Rees and Smellie 1989; Chapman and Smellie 1992). Interpretations of palaeogeography and volcanic arc evolution in the northern Antarctic Peninsula region have been revised in the light of these new age assignments (see Rees 1993 for details). The new age assignment for the Hope Bay and Botany Bay assemblages provides the first direct evidence that terrestrial sediments were deposited on a magmatic arc in at least parts of the northern Antarctic Peninsula during the Early Jurassic. It is noteworthy that marine beds of Jurassic or younger age are unknown from the central area of the northern Antarctic Peninsula. It seems more probable that magmatic arc uplift occurred and an appreciable landmass existed in this area from Early Jurassic times onwards, rather than from the Early Cretaceous as suggested previously (e.g. by Farquharson 1984).

The present revision indicates that the ages assigned to a number of other Mesozoic gondwanan floras must be reappraised, particularly those from Argentina which had been dated on the basis of their close similarity to what had become regarded as the earliest Cretaceous assemblage from Hope Bay. Further studies of the kind presented here are necessary in order to ensure that reconstructions for instance, of palaeogeography and palaeoclimatic change are not severely compromised by the use of inaccurate raw data.

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APPENDIX

Natural History Museum (NHM) registration numbers and corresponding original British Antarctic Survey (BAS) station numbers assigned to specimens studied for this paper.

NHM number	BAS number	NHM number	BAS number
V.63420	(no number)	V.63606	D.8951.16
V.63423	(no number)	V.63607	D.8953.8
V.63590	D.8919.1(A)	V.63608	D.9003.1
V.63591	D.8919.1(B)	V.63609	D.208.1(1)
V.63592	D.8919.1(X)	V.63610	D.208.1(4)
V.63593	D.8919.1(Y)	V.63611	D.208.1(5)
V.63594	D.8919.2	V.63612	D.208.1(6)
V.63595	D.8919.3	V.63613	D.208.1(A)
V.63596	D.8919.4	V.63614	D.208.1(B)
V.63597	D.8919.5	V.63615	D.208.1(C)
V.63598	D.468.7	V.63616	D.208.1(K)
V.63599	5826	V.63617	D.208.1(L)
V.63600	D.8868	V.63618	D.208.1(M)
V.63601	D.8913.2	V.63619	D.208.1(P)
V.63602	D.8951.5	V.63620	D.1.1
V.63603	D.8951.8	V.63621	D.8890.1
V.63604	D.8951.9	V.63622	D.8890.2
V.63605	D.8951.12	V.63623	D.8890.3